



Development of Low Cost Biogas Capture System for Small Scale Urban Farms

An Interactive Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in fulfillment of the requirements for the Degree of Bachelor of Science

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Abstract

This report explores the current state of urban agriculture in the United States, the benefits of anaerobic digestion as a renewable energy source, and the potential for biogas capture at a farm, Nuestro Huerto, a small urban farm in Worcester Massachusetts. Gas handling systems are investigated, and a design is proposed for compressing and storing evolved gases from the Nuestro Huerto digester.

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1.0 Introduction

In the United States and throughout the rest of the world, farming has been humanity's source of nutrition and sustenance since before recorded history. The planting and raising of staple crops has formed the livelihood of much of the population up until recently when that task has fallen to the hands of a select few employing industrialized techniques in order to maximize outputs and minimize overhead costs. This growth in industrial agriculture has depended on the deployment of synthetic fertilizers and other agro-chemicals.

One potential supplement to the reliance on these technologies to provide cheap food to large populations is the tactic of distributed production in the form of urban agriculture. Urban agriculture in America takes the form of community gardens, home production, and small-crop greenhouses, but many have theorized about its potential to be scaled up, producing more food closer to population centers. Through advanced high crop-density technologies such as greenhouses, climate control, soil remediation, biodigestion for waste disposal, energy, and fertilizer, and hydro and aeroponics to reduce the space and growing time needed to produce a given quantity of a staple crop. (Greensgrow Farms, 2014)

Currently much of this technology is in the development and testing phase, but some of it has reached a point of moderate functionality and has been deployed on the small scale to the benefit of its early adopters. A noteworthy example of this technological integration is the anaerobic digester. Already in industrial use at many wastewater treatment plants and some farms with livestock to handle waste, anaerobic digestion is a technology as old as the microbes upon which it relies. When organic waste containing energetic hydrocarbons such as sugars, starches, fats, and proteins is given to the consumption of bacteria in the absence of oxygen (underwater) the chemical oxygen demand (COD) inherent in that material's decomposition is transferred with some losses to the waste product of the bacteria's digestion, methane. The high energy methane can then be used as fuel for heating

the reaction further or for powering systems at the digester's location or functions ancillary to the digester's function. (EPA-AgSTAR, 2012)

Among the problems that must be addressed in implementing this sort of system is the machinery that must capture and collect the gas evolved from the biological sludge contained within the digester. To simply affix a pipe to the top of the digestion vessel is not sufficient as it does not address variability such as gas pressure and gas production rate. There are also aspects of a collection system that must be designed around the intended use of the gas, and not simply the output of the digester. The user of the gas will need to have the capacity to store the gas, as well as pressurize it to a variety of pressures depending on the intended use, be it for heating, cooking, heating the digester itself, or direct resale of the energy back to the electrical grid for profit.

In large scale agricultural operations, typically dairy farms, digesters take the form of huge vats into which manure and waste is pumped and methane is pumped off of the top and into pipelines and storage containers, but on the private or small scale, digesters typically store their gas output in plastic drums at low pressure using cheap plumbing components and low-tech water gaskets. Some higher technology versions will use flexible membranes, but almost none employ any significant compression to increase storage capacity and gas usability.

In Worcester Massachusetts an urban farming outfit called Nuestro Huerto, the sponsor of the project, has installed an anaerobic digester and they are seeking a way to make use of the gaseous byproduct. Their digester currently has no means of capturing evolved methane, and it is the goal of this project to design one that will meet the needs and budget of the sponsor as well as be reproducible for other small farms looking to employ this sort of developing technology. (Nuestro Huerto, 2014)

2.0 Background

2.1 Biodigestion and Agriculture

The agricultural industry in the United States uses 54% of the land and involves only 2% of the population. Despite such a large industry being operated by such a small population sector, 97% of the 2.2 million farms are owned and operated by families and family organizations. (Bureau of Labor Statistics, 2013) The reason that such a huge industry is operated by such a disproportionate population sector is because of the way agriculture is practiced. In America large pieces of land are farmed by few workers using advanced technologies such as mass irrigation, synthetic fertilizer, extensive mono cropping, and pesticides sprayed from the air. These methods are not optimum, but they are what it takes to provide the nation with food and still have products left to export.

Farming is one of humanities largest consumers of resources. Since 1950 food production has increased by 262% with actually a slight, 2%, decrease in resource usage. (American Farm Bureau Federation, 2014) Even so, irrigation for crops and pastures still consumes a large part of all fresh water used and the production of synthetic fertilizers is still needed to meet the demands of the population.

The environmental effects of such resource use are, not surprisingly, problematic. Fertilizer runoff chokes out aquatic ecosystems, vast amounts of energy are needed to synthesize fertilizers, and water is essentially wasted as only a portion of the water used for irrigation actual makes it into the crop's roots while the rest carries fertilizer off to the watershed. In the farming of livestock, tons of manure is left to decay in the open consuming oxygen and releasing the greenhouse gasses methane and carbon dioxide. Energy is consumed to run equipment and even to dispose of waste.

So what if we could kill two birds with one stone? What if we could dispose of agricultural waste and at the same time produce power and fertilizer? This can be done using the method of anaerobic digestion, the microbial decomposition of organic material in the absence of oxygen. Some of the earliest bacteria on earth

made use of an uncommon metabolic pathway in which they used carbon as an energy source but the energetic compound methane as a waste product. This pathway was advantageous in environments where organic material would lay submerged in still water, removed from atmospheric oxygen. These bacteria are still with us today in bogs and swamps, but now many of them also live in the digestive tracts of animals, helping to digest food for a small cut of the energy gains. It is the substantial cultures of methanogenic bacteria living in the digestive tracts of cows that cause their manure to be valuable for setting up controlled digestion operations. (Fry, 1973)

Humans have been familiar with the natural process of anaerobic decomposition since antiquity, but it was not until recently that we began to exploit it to its fullest potential. It is believed that the first purpose built digester that can be reliably documented existed in Bombay India around 1900. This digester was designed to extract energy from cow manure and leave the nitrogen containing compounds for use as fertilizer. Today, India is still a hub of anaerobic digester research as in its rural areas 800 million tons of manure is produced per day and the farmers cannot afford to waste the energy and nutrients contained in the animal waste by simply drying and burning the manure as has been customary. (Fry, 1973)

There are several ways to exploit the biological capacity of methanogenic bacteria. There are two main modes of operation and many configurations within those modes. These are batch loaded and continuous feed or "plug flow." Both must allow the slurry to go through a sequential process but batch digesters allow the digestion to occur over time but in a single space while plug flow digesters allow the reaction to occur over a single spatial continuum simultaneously. Each mode has its advantages and disadvantages. Batch digesters are biologically more stable because the entire volume is held at the same stage of digestion but they do not allow for continuous inputs and outputs the way plug flow digesters are able. Plug flow however is difficult to build and maintain as the slurry must remain separated between phases of the digestion process, and the input of new slurry must uniformly advance the standing mixture of slurry without disturbing the boundaries between reaction layers.

Each mode of operation makes an appearance in the practice of industrial digestion. Although the plug flow mode is significantly more common, batch digesters are still effective when the waste being treated is dilute such as wastewater carrying suspended organic solids. (EPA-AgSTAR, 2012) The two most common digester technologies are the lagoon and the Up-flow Anaerobic Sludge Blanket, both examples of plug flow. In lagoons the flow can be either in the horizontal direction, that is slurry entering on one side and effluent leaving on the other, or in the vertical direction, slurry being pumped out of orifices at the bottom and making its way to the surface for removal or post-treatment. In the Up-flow Anaerobic Sludge Blanket slurry enters at the bottom of a vertical tank and must make its way upwards through a layer of suspended sludge, which contains the majority of the microbial mass. In less common reactor styles, fixed films, contact digesters, and Induced blanket digesters, the movement of material is similarly in the vertical direction through successive layers of material. (Shannon, 2002)

Figure 1: Empty Lagoon Digester



Figure 2: Covered Lagoon



Figure 3: A Plug Flow Digester

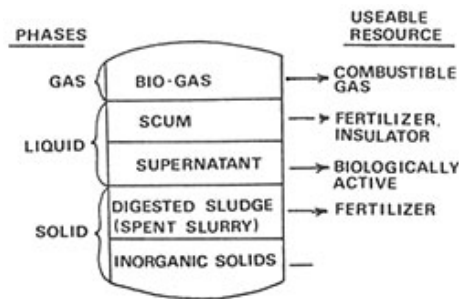
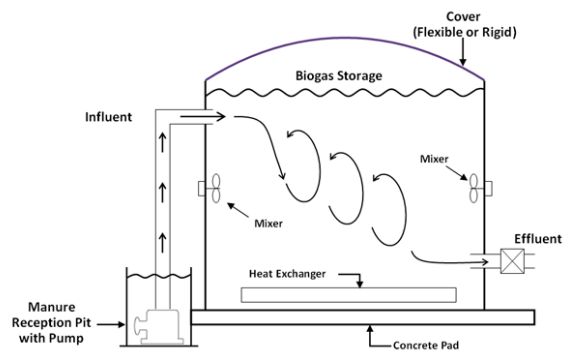


FIG.2 Layering of By-Products In the Digester

Figure 4: Schematic of a Mixed Digester



Currently in the United States anaerobic digestion is in place at an EPA estimated 239 commercial livestock locations with the overwhelming majority of them being at dairy producing locations. These digesters are currently producing over 400 kWh per year, a 25-fold increase since the last decade. Many more sites lend themselves to anaerobic digestion projects, which would have the potential to produce over 24 million MWh per year.

Table 1: Electricity Generation Potential for Biogas Recovery Systems at Animal Feeding Operations (EPA-AgSTAR, 2012)

Animal Sector	Candidate Farms	Energy Generating Potential		
		MW	MWh/year	MMBtu/year
Swine	5,596	804	6,341,527	21,643,632
Dairy	2,645	863	6,802,914	23,218,346
Total	8,241	1,667	13,144,441	44,861,978

According to the National Renewable Energy Laboratory Biogas produced from animal, human, and landfill waste “could displace about 5% of current natural gas consumption in the electric power sector and 56% of natural gas consumption in the transportation sector.” Although with natural gas accounting for 25% of US electricity production and 3.4% of transportation fuel, biogas would ultimately replace only about 2% of all energy consumption. (NREL, 2013)(Center For Climate and Energy Solutions, 2010) With this being the case the primary motivation to implement the technology is to recover energy from existing waste streams and offset greenhouse gas emissions produced by traditional disposal systems such as landfill, composting, and incineration.

2.2 Urban Agriculture

One type of agriculture that could benefit greatly from the development and implementation of anaerobic digestion technology is the urban agriculture movement. Urban Agriculture is a growing practice of producing food through the use of city gardens, personal greenhouses, and high crop density spaces within cities and populated areas (Greensgrow Farms, 2014). One of the main intentions of urban agriculture is to produce food while decreasing resource consumption, mainly land water and fertilizer. It is easy then to see that the mission of urban agriculture falls well into line with the agricultural potential of anaerobic digestion. An urban agricultural operation that adopted anaerobic digestion systems would be able to fairly seamlessly integrate the digestion system into existing necessary farm functions, such as fertilization, irrigation, heating, and lighting. In similar ways digesters are beneficial to large traditional farms.

The start of the urban agriculture movement is difficult to define as growing food has always, and will hopefully always be a part of the human experience wherever we may go. In many ways the movement began around the 1970's when manufacturing began to drain out of urban centers due to more mobile capital, automation, union pressures and the availability of imported manufacturing. This urban recession left large amounts of property unused, and sometimes even entire buildings would be abandoned or even burned for lack of profitable use. As highways allowed workers to commute from city outskirts and unemployment went on the rise, it became viable for many landlords, whose rents were quickly falling to file fraudulent insurance claims for self inflicted arson. This dramatic devaluation and abandonment of property left a niche however, into which urban agriculture fit nicely. (Philpott, 2010)

"Agriculture is a residual activity within imperfect markets. As such, it is conducted opportunistically and with relatively little investment. Farmers are more induced in self-subsistence rather than looking at income opportunities" – Rachel Nugent, *Growing Cities, Growing Food*.

In the 1990's Urban agriculture gained a greater air of legitimacy as urban garden projects began to be used as teaching tools for the disadvantaged and a source of simple employment and community connectedness. The types of urban growing operation also increased during this time. From window boxes to dirt-lot greenhouses, urban agriculture has become a considerable aspect of city life to many and seems to only be increasing in prevalence. (Philpott, 2010)

There are many ways to conduct an urban agriculture operation. As stated earlier the scope of a project can be quite small, technically a window box can be considered urban agriculture so long as it provides some form of utility, growing herbs or vegetables. Or the project can be quite large, potentially filling the entirety of indoor spaces or building rooftops such as the one pictured in Figure 5 below. Operations can also exhibit a variety of farming methods. Many employ greenhouses to maximize heat retention and minimize water loss to transpiration. Those that operate in open spaces that may not be well suited for the growing of crops can employ raised bed technology, a system that isolates crops and their root systems from soil that may be either nutrient deficient or high in dangerous heavy metals. The motivation for many of these projects is resource efficiency and for that reason use systems such as rain collection and composting. Even with these technologies the practice is still young and the possibilities for future technological development such as hydroponics and aeroponics is exciting to say the least. (Boer, 2013)

Figure 5: Lufa Farms' 31,000 ft² greenhouse on top of a building in Montreal.



Status In Worcester

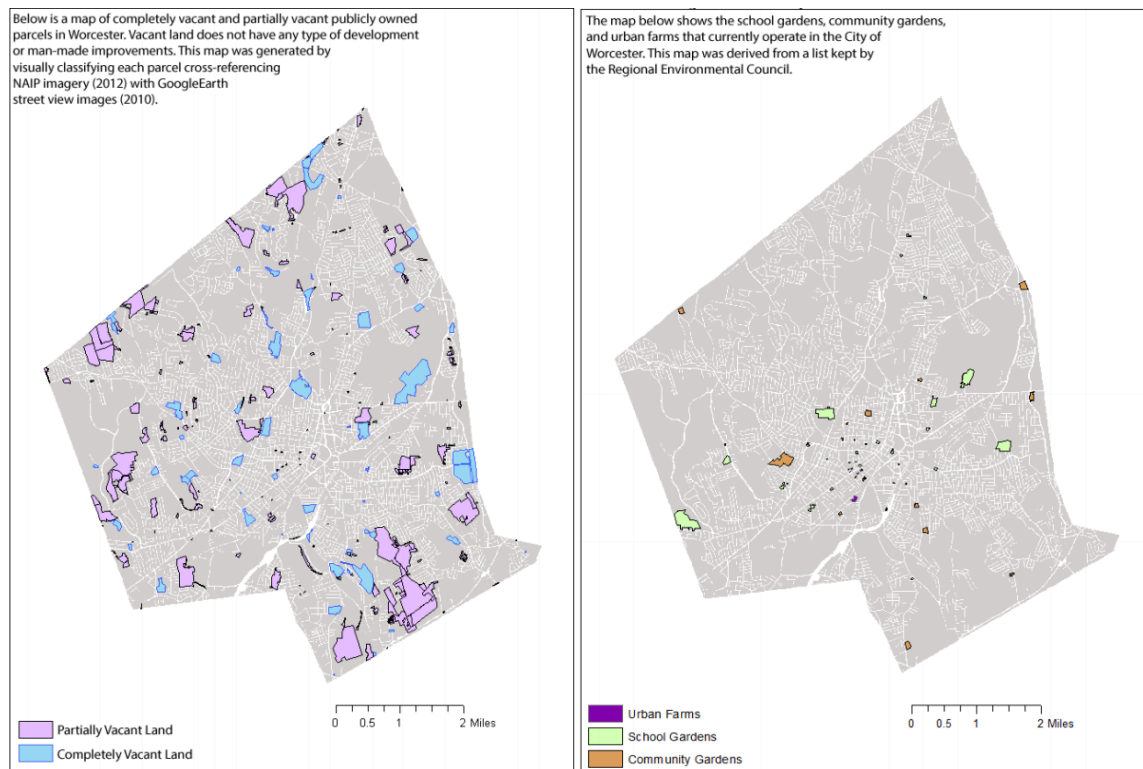
One city to which urban agriculture is relatively new is Worcester Massachusetts. In Worcester there is little in the way of organized or city promoted urban agricultural initiatives. Zoning policies do not contain specific zonings for agricultural operations in urban settings, but do afford that food be produced within any zoning except residential. Among the only actions taken specifically addressing urban agriculture was the 2006 Open Space and Recreation plan, which stated as goals:

- Encouraging community gardens within more densely populated areas.
- Protecting tax foreclosure property by transferring significant parcels of open space that can be preserved as conservation land or utilized as community gardens to Worcester Conservation Commission.
- Promoting community gardens, identifying parcels;
- Safeguarding agriculture through protection of existing and potential sources of arable land in community garden model and provision of appropriate municipal supports for farmers' markets;
- Using vacant lots for "urban gardening" program

(Worcester Food and Active Living Policy Council, 2013)

Despite these apparent efforts to promote urban agriculture, potentially arable land in Worcester remains largely unexploited. A study conducted by a team of Worcester Polytechnic Institute students found that the land usage by agricultural operations is only a small fraction of the land available, and a very small fraction of the land in total. On the next page is shown two figures, the first with the current state of agricultural operations in Worcester by parcel and the second with the distribution of vacant and partially vacant land by parcel. The study, titled *Mapping the Potential For Urban Agriculture in Worcester*, was conducted with the intention of determining the steps necessary to actually promote the expansion of urban agriculture in the city of Worcester. The study found there to be 2562 acres of vacant or partially vacant land of which little was slated to be developed in an agricultural capacity. (Ringenbach, 2013)

Figure 6: Vacant Parcels (Left) and agriculturally purposed parcels (Right)



With the increasing population and decreasing resource availability the task of supplying the masses with sustenance has been dealt with by devoting huge tracts of land and resources to producing refined products that can be sold at low prices. The current food system is a low value, linear operation. Food is produced centrally and then the low quality distillates of the original crop are distributed to urban centers and sold at central locations at low cost. A preferable vision of the future of food production looks like this: The crop is grown in a decentralized fashion, not so much small demonstration gardens at schools and community centers, but commercial scale urban farms relying on high yield density strategies and selling the product in near raw form at or near the production sites. These small farms could become commercially viable due to the increased value of the food produced and the decreased cost of distribution and refinement. The advantages to this decentralized structure are many. Resource conservation, decreased transportation costs, and community involvement are just a few of the ways this strategy will better the lives of those in the community.

2.3 Biodigestion in Urban Settings

With such a large potential for urban farms, there arises a great need for space, energy, resource, and time saving technologies and practices. Urban agriculture is itself a resource saving technology, and so when coupled with a technology such as a biodigester the beneficial effects are compounded, allowing food to be produced in potentially large quantities by small, distributed, farms striving for near closed cycle operations. The challenges that are amplified by moving farming into the urban setting are often the same challenges that are mitigated through the employment of an anaerobic digester.

2.3.1 Energy for Climate Control and Power

When food is produced locally, the crop is largely subjected to the local climate, which could be significantly less optimal than the climate of those areas intentionally selected for centralized crop production. Technology, as it so often does, offers a way around this problem. Covered greenhouses insulate crops from harsh weather conditions as well as trap heat that plants need to grow. Anaerobic digesters augment this function by supplying energy that can be used in conjunction with the energy trapped by the greenhouse. Anaerobic digesters also require a high operating temperature, and by having the digester occupy the same space that it is heating the efficiency is further increased.

2.3.2 Utilization of Organic Wastes

Agricultural operations generate large amounts of waste. Plant stocks, rotted produce, byproducts of food preparation, and pruned leaves are all necessary refuse generated when growing plants for food. Fortunately anaerobic digesters are particularly good at turning organic waste into resources. The waste generated and subsequently consumed for energy and fertilizer by the farms and digesters would be an example of an approximately closed cycle operation, that is an operation where the same material is continuously cycled, being reconstituted through endothermic and exothermic processes. Most processes in nature exhibit this closed loop structure and the human processes of the future would do well to mimic them.

2.3.3 Fertilizer Generation from Waste

Among the neat tricks we can goad microbes into doing for us is the fixation of nitrogen. In the early days of farming, fertilizer had to either already exist in the substrate or be added by natural sources. The Native Americans knew that corn would grow better if the seed was buried with a fish. The colonists in the Americas did not see the value in this behavior, but they were being shortsighted. The decomposition of fish by microbes releases large amounts of ammonia, (NH_3) a nitrogen-bearing compound that plants crave. Other popular sources of nitrogen are bone meal, urea, potash and ammonium nitrate, the first two being natural animal byproducts, the third a naturally occurring mineral, and the last a synthetic compound. (Penn State College of Agricultural Sciences, 2014)

Nitrogen in its diatomic gas form abounds in the atmosphere and is actually air's majority constituent, but for nitrogen to become available in the soil from the air it must be fixed into Nitrates, oxygen-bound nitrogen by lightening or bacteria. Anhydrous ammonia was first artificially synthesized during the Second World War for use in explosives¹ by Fritz Haber², a German chemist, and later enabled the massive growth of industrial agriculture after the war. The Haber-Bosch process combines hydrogen from the fossil fuel natural gas with atmospheric nitrogen in a high heat environment and is still used to fertilize the majority of commercial food production. The energy expended by consuming natural gas and heat accounts for 80 to 90% of the cost of commercial fertilizers. (Moustier, 2012) If this gratuitous energy expenditure were avoided by converting existing problematic organic waste into nitrates and ammonia through the natural pathways invented by microbes, the world's food production could break its dependence on an unsustainable practice. Biodigestion makes this switch not only possible, but also easy, using material that would otherwise be a disposal nuisance.

¹ The Oklahoma city bombing of 1995 used a truck full of industrial agricultural fertilizer)

² Haber also invented Zyklon B, the popular industrial agriculture insecticide used in Nazi concentration camp gas chambers.

2.4 Nuestro Huerto

One particular urban agriculture operation will be a focus for this project as the project ultimately pertains to the development of a system tailored to a specific system at a specific location. In Worcester Massachusetts there is an organization known as Nuestro Huerto, Spanish for “Our Garden.” As it’s name suggests, Nuestro Huerto is a community garden type operation with the mission of serving “as a community asset that offers equitable access to healthy produce, educational opportunities and an environment that fosters a diverse, open and inter-generational community.” They began operation as a collection of raised beds in an unutilized industrial park, and through their community involvement, have grown to serve high nutritional value mixed vegetables to community members through farmer’s markets and restaurants, aided by the Community Supported Agriculture program and the Worcester Roots Project. (Barker, 2014)

At one of Nuestro Huerto’s Industrial properties a team of WPI students has installed a roughly one thousand liter biodigester just outside of the greenhouse that the farm uses to grow crops in the summer, and germinate their seeds to get a head start on the growing season. The digester is roughly the size of a small dumpster and is composed of an industrial plastic cubic container surrounded by fiberglass insulation and a skin of plywood and construction sheathing.

Figure 7: 1000L Digester Installed Outside the Nuestro Huerto Greenhouse



The Nuestro Huerto Digester is what is called a *thermophilic* digester, meaning that the bacterial growth is promoted by a high heat environment and therefore the biological process occurs much more quickly. By utilizing the higher temperature species of bacteria, the retention time, that is the time a give unit of waste must remain in the digestate, can be reduced by as much as a factor of four, from an average of 17 to an average of 4 days. (Gagnon, 2014) Because a high temperature must be maintained for the operation of the digester, there is a heating mat attached to the underside of the digester vessel and fiberglass insulation and thermal wrapping fitted to all *hot* surfaces.

Figure 8: Heating Mat on Vessel (Left) Insulation Being Installed (Right)



A gas capture system has yet to be installed onto the digester, and as the digester nears completion the need for such a system will only increase. With methane being a potent greenhouse gas and fire hazard, the clock is ticking to implement a gas capture strategy.

3.0 Methodology

With an anaerobic digester of moderate size getting near to steady operation, the need for gas capture becomes increasingly more apparent. However, it will not suffice to simply build a rig that accumulates the gaseous methane; there are many more factors at play in determining what type of system will not only capture byproduct gasses of the reaction, but capture them in a way that is the most useful and convenient for the end users, the sponsors at Nuestro Huerto. For a project of this kind, where a product is to be delivered to a sponsor, it is important to assess the needs of the sponsor so that the product delivered is satisfactory and does not leave the sponsor with residual concerns or desires. In the case of this particular sponsor, the needs must be determined first so that all other actions can cater to them and in doing so be done efficiently. The following sections outline a standardized engineering design process, as it is adapted for use with this project. Each section can be viewed as sequential objectives, each with its own sub-objectives.

3.1 Phase 1: Needs Assessment

In building on the work of a recent IQP project, there is a need to devise a device to handle the gas produced in such a way as to meet the needs of the project's sponsor. To ascertain these needs, the sponsor has been consulted to discuss the specific parameters that are sought for the product. Early in the project, on March 28th, 2014 an interview was scheduled with the sponsor, the director of Nuestro Huerto, Amanda Barker. In this interview the current state of affairs at the industrial park site was discussed, including the progress made on completing the biodigester by the digester team. Due to the intermediate state of completion of the digester, it was not yet known how much gas the device would produce. For this reason the solution has to be able to accommodate a wide range in both the storage quantities and the production rates of biogas/methane.

A major portion of the discussion was devoted to the safety ramifications of such a solution. In many of the concept designs some form of gas compression would be employed and were this to be the case, an entirely new set of safety concerns would be introduced not only based on the flammability of the gas being stored, but on the increased quantity, increased concentration, and additional energy inherent in pressure storage.

Due to the amount of space available on the premises of the digester, size was also a major consideration in creating and choosing designs. The device would ultimately need to take up minimal space and exist relatively unobtrusively, not obstructing any of the everyday activities preformed at the greenhouse.

Other concerns, needs, and intentions raised during the interview with Amanda included the source of supplemental electrical power, the possibility of refining the gas, and the way the gas might be used. Due to the environmentally conscious mindset harbored and promoted within the Nuestro Huerto culture, it was important to Amanda that supplemental energy come from a responsible source, for which reason the option of powering ancillary systems using photovoltaic solar panels will be considered. As for refining the gas, such an investment may not be immediately necessary and can be viewed as a future goal worthy of some thought but not an immediate detailed design proposal. Lastly, and in many ways most importantly, the gas must be in a usable state. For heating and cooking, the primary application of most biogas sources, that generally means some pressure and relatively high volumes. As a necessity, the device will need to be able to store gas that is generated of periods of time from the order of hours all the way to the order of weeks without any significant leakage or gas contamination by oxygen.

3.2 Phase 2: Problem formulation

After ascertaining the major needs and desires of the sponsor, it is helpful to form a discrete problem statement. A viable problem statement in this project is: To research methane gas handling technology as it pertains to anaerobic digestion, and design a functional example of a gas handling system appropriate for the sponsors

and the existing gas production system while considering the possibility of future implementation.

Bellow are the specific knowledge based goals presented as directives and further guiding research questions.

3.2.1 Research Goals

- Better understand the operations at Nuestro Huerto.
 - What resources are in greatest need to their operation?
 - What resources are available to be used as inputs?
 - Given that the biodigester has already been installed, how does it interact with these resources?
 - What are its inputs and outputs?

3.2.2 Design Specific, Detail Problem Statement

The solution must safely contain and dispense the byproduct gasses of the anaerobic digester installed at Nuestro Huerto in such a way that they can satisfy a portion of the organization's energy expenditures. The solution must be cost appropriate for the extent of its service. The solution must seamlessly integrate with the existing digester. The solution must be reliable and not interfere with usual procedures. The solution should be fairly reproducible.

3.3 Phase 3: Abstraction and Synthesis

In beginning the conception of a solution like this, it is important that a diverse set of conceptual solutions be generated. In creating many distinct concepts to achieve the same goal it is possible to consider more unique and better-suited concepts. This way it is ensured that as much of the solution space as possible will be covered before the initial rounds of narrowing down. This step is also called Ideation, and it can be conducted through strategies such as brainstorming and concept webs. What is important at this phase is not that the ideas be high quality, but that they be diverse. The final solution may not even be in the set that is generated during the first round of ideation.

For this project the ideation strategies deployed included, whiteboard drawing, branched abstraction from seed concepts, ruminative brainstorming, and a strategy that was found particularly effective given the DIY nature of the project; examination of available materials. Essentially this strategy is to look over the parts and components that can be found near the industrial site and in personal reserves and attempt to find use in them. In DIY type projects this can be very effective because it increases the likelihood that the purchase of expensive components can be circumvented by designing around free or low cost scavenged parts. A potential downside to designing this way is that I can impact reproducibility since others intending to reproduce the design may not have the same parts available. Because reproducibility is a secondary goal for the project the design will attempt to use only common and available materials.

3.4 Phase 4: Analysis

Several possible solutions generated in the previous step will be critically evaluated and the solution set will be thinned. Phases 3 and 4 are the least linear phases in the design process. By conducting subsequent rounds of this generate and select process a fully designed solution was honed that most effectively meets the need within reason. Several strategies exist for doing this honing and the method that is used for this project is the decision matrix. The exact matrix used for this project can be found as Table 2 on page 28. To conduct a decision matrix, the available options for each specific function of the system must be collected and listed down the side of the matrix. Then a number of parameters must be outlined. In the case of this project, those parameters were effectiveness, cost, reliability, and ease of use. These parameters are listed across the top of the matrix, and underneath them, a weighting factor is assigned. The weighting factor is a user defined decimal fraction that represents the relative importance of each parameter to the function of the subsystem being decided. The weighting factors should add up to one that way the relative importance of a parameter is made sure to be relative to the other parameters involved. To use that table, each option must be assessed against each parameter. The assessment can be made either on a common scale such

as a one through ten scale or a scale with as many gradations as there are rows in the table, or on an ordered ranking wherein four options would each receive a number one through four based on relative strength regarding that parameter only. The advantage to using a general scale is that it allows for degrees of superiority and equal rating for those too close to call, while the advantage to a relativistic ranking is that the numbering is less arbitrary as it can be formulated given only the option's relative superiority to one another.

For this project a relativistic scale was employed to reduce arbitrage in the assessment of concepts. In truth though arbitrage cannot be eliminated from such a design process as at some point the designer will be forced to make at least one judgment call, thus introducing the subjectivity that is always found in concepts borne of a human designer. In the face of these subjectivities it is the designer's merit that determines the strength of the decision.

Once numbers have been assigned to every option in every parameter, the table is full. At this point the numbers are multiplied by the weighting factor and summed within their rows to determine overall superiority. The entire process can quickly be conducted using a Microsoft Office: Excel spreadsheet. The outcomes are included in the *Findings* chapter along with Justifications for the design choices made subjectively.

3.5 Phase 5: Implementation

Fundamentally, implementation is not within the scope of this work. A design will be formulated using the design process, and the construction will be outlined, but not brought to fruition immediately. That isn't to say that the design formulated will never be implemented, just that the results of this work will only go so far as to document the process up until this point. The ways in which the device is documented and evaluated should reflect the needs of the sponsor. It is the desired outcome that the solution implemented meet all of the sponsor's needs to the furthest extent possible and the conclusions drawn at the end of the body of the project will regard the extent to which the solution meets each of the sponsor's individual needs. Each need identified is concluded either by explaining why the

solution was sufficient or by explaining why the solution was insufficient and what could be done to make the solution more sufficient.

Because a prototype will not be created, the results section here will be composed of a detailed design description and the theoretical evaluation of the prototype. The conclusions section will be composed of the designer's personal take on the outcome as well as comments about the process and the recommendations for moving ahead. Should construction and installation be addressed prior to publication, the documentation will be included as a log in the appendices.

4.0 Design

As described in the Methodology, the design process was conducted using an existing engineering design process. (Volland, 2013) The advantage to using an analytical process is that it guides the designer through steps which promote the ideation of many and diverse concepts and subsequently provides a means of systematically converging on a solution. The two steps of this process that specifically pertain to the prototype are listed below and this section seeks to illustrate how these steps are applied to the problem at hand. There is a detailed description of what each step entails and its function in the *Methodology* section.

4.1 Abstraction and Synthesis

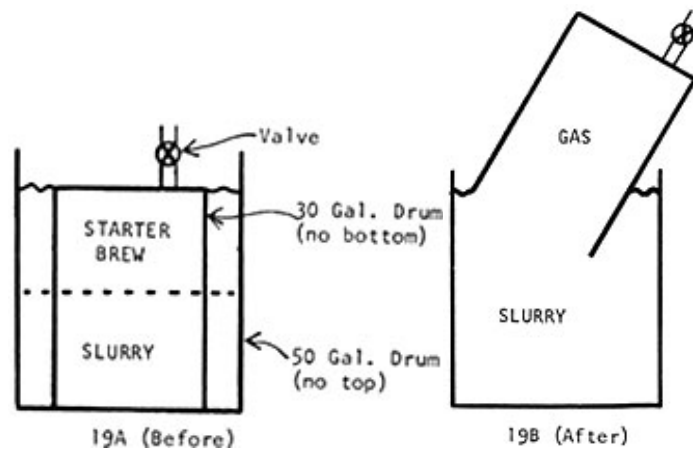
For the abstraction phase of the process a list was generated containing many of the common gas capture mechanisms as well as some original concepts. These include most notably, the floating hood, flexible membrane, direct output, low-pressure, and high-pressure compression. For each an understanding of how that system would be constructed is reached using examples from existing systems and conceptual sketches for those that are not already being used in the field.

4.1.1 Floating Hood

By far the most common gas capture scheme, the floating hood relies on one container making a seal with water in another container. The overall function is roughly analogous to a piston, and stores as much volume of gas as the volume of

the container that makes up the moving portion of the piston. Methane that comes from the digester is made to bubble through the water enacting a purification effect. The gas is then unable to escape the moving container until a valve on the top of the container is opened allowing the gas to flow through a pipe to its end use. Because pressure in the hood is expressed as a difference in the levels of the water inside and outside the hood generally only a few inches of water pressure can be developed on the gas unless water is allowed to be displaced entirely out of the first container. In better-designed versions of this method the hood is often supported by rails of some kind to prevent it from toppling and spilling the gas. (Fry, 1973)

Figure 9: Example of a Floating Hood System



http://journeytoforever.org/biofuel_library/MethaneDigesters/MD5.html

Were the floating hood system to be implemented at the sponsor's digester, it would take the familiar form of a smaller barrel inverted into a larger and filled with water. To prevent the water from freezing in the winter, antifreeze would be added. The gas-in pipe would be affixed to the bottom of the larger barrel, while the gas-out pipe would be affixed to the bottom of the larger barrel with a rigid pipe extending to the water's surface to allow the gas to exit without interfering with the moving, smaller barrel. To keep the moving barrel moving directly into and out of the water, a pair of telescoping pipes would be affixed inside each thus acting as the guide rail.

4.1.2 Flexible Membrane

The next most common design for gas capture in small digesters, the flexible membrane system comes in a wide variety of constructions. In smaller cases easily found vessels are used for gas storage such as balloons, inner tubes, or plastic yard bags. In larger cases the vessels are custom built from large sheets of rubber or plastic. More common in industry is for the sheet to cover the digestion pool, and expand as gas is produced. The is structure is used in a few examples of private digesters, (Hren, 2012) but more common in these cases is to use a vessel such as a plastic yard bag which expands without exerting large pressures and can be attached around the lip of base containers such as buckets or barrels.

Figure 10: Examples of Flexible Membrane Systems



<http://www.biogasaustralia.com.au/biogas-generation/digester/digester.html>

Figure 10: Continued



<http://www.homepower.com/articles/home-efficiency/equipment-products/home-cookin-homemade-biogas> (Left)

<http://nefb.wordpress.com/2012/07/24/pilot-project-uses-new-technology-to-capture-energy-from-hog-manure/> (Right)

Were the flexible membrane system to be implemented for gas capture at the Nuestro Huerto site, it would be constructed by affixing contractor bags to the tops of barrels such that when empty, the bag fills the barrel as though it were a trash can liner, but when filled it assumes the opposite form, allowing gas to fill the volume of both the barrel and the bag. This construction is low cost and involves no water, meaning that several units could easily be constructed and strung together creating a potentially very large gas volume. A drawback to this system is that it would not support pressure and would be vulnerable to membrane rupture. Adding a layer of burlap over the plastic to protect against cuts and punctures could mitigate rupture risk. To allow for pressure to be applied to the gas, some kind of pump might still be necessary, meaning that this system could be used to supplement one of the higher-pressure system mentioned next. To utilize a membrane that exerts pressure when expanded is desirable when pressure is needed immediately, but it possesses such negative aspects as a slowed reaction rate due to elevated concentration of reaction byproducts and leakage associated with gas seeping through seals, gaskets, and fittings. An ideal system would apply a constant, very low, gas pressure so that oxygen does not seep into the storage (which is why negative gas pressure is to be

carefully avoided) and too much methane is not lost as would occur in a higher-pressure system.

4.1.3 Direct Output

Direct output is in essence not even a gas capture strategy. It is more a gas utilization mode and one that is appropriate in only specific situations and circumstances. The reason gas storage is so important to a digester is that the gas generation and gas utilization rates are nearly guaranteed not to coincide in an appreciable way. For uses such as cooking and electrical generation storage is needed to store gas that is slowly produced so that it can be used at a higher rate for a shorter time. For instance the digester may need to run continuously between meals to produce enough gas for cooking. It may need to run all day to produce enough gas to run a generator for a few minutes. For these reasons direct output is almost solely suited to heating applications where the gas can be used continually at low rates, or in the event the digester is able to regularly produce at a usable rate.

4.1.4 Low Pressure Compression

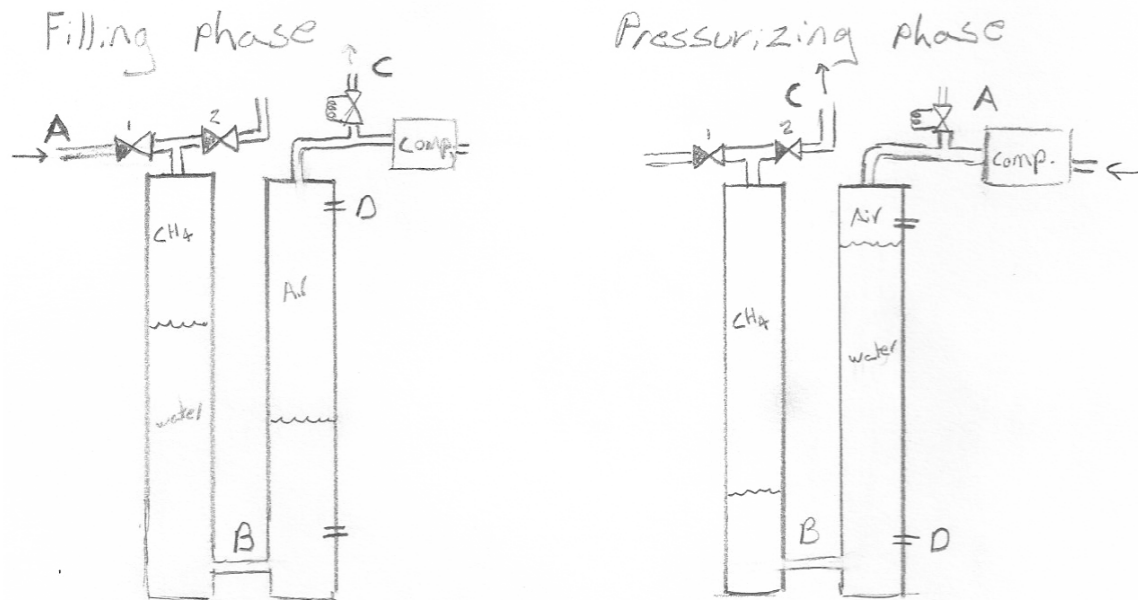
The compression of natural gas is a popular means of storage in industry. At farms, water treatment, and food processing plants, powered mechanical compressors move gas from the digester vessels where it is often stored at negligible pressure, within a few psi, to pressurized storage tanks which can hold gas at as high as 3000 psi, depending on the size and construction of the tank. Within the context of this project low-pressure compression will be defined as within the pressure regime offered by typical air compressors and compressed gas equipment. The upper limit for this regime is between 100 and 250 psi depending on choice and quality of components used. Low-pressure compression is not often implemented in home use systems likely due to the technical complexity and in systems where the capital is present to implement such technology it may be foregone due to the advantage conferred at that scale by cryogenic gas storage.

The natural gas industry almost exclusively uses cryogenic storage of liquefied natural gas (LNG). The reason LNG is effective is that to store large quantities of gas at pressure represents a need to construct impossibly strong

containers, while even large containers can be built with the insulation and cooling necessary to lower the temperature to the point where methane exists as a liquid at atmospheric pressure, thus enabling methane to be stored at over twice the energy density of compressed natural gas with far lower risk. Among the only instances of compression supplanting liquefaction in industry is in the case of pipelines. Large tanks cannot be made to store gas at high pressure because the operating pressure of a cylinder is inversely proportional to its diameter. Pipelines however have relatively low diameters and would be unreasonable to thermally insulate due to their length. Thus, in order to pipe methane it is advantageous to compress the gas.

Were low pressure compression to be implemented at the Nuestro Huerto site, it would have to be custom engineered, as such technology is not generally employed in these circumstances. To purchase equipment used in industry would be cost prohibitive, and thus a fluid pressure transfer system would be constructed using standard plumbing parts. A rough diagram is presented bellow showing the manner in which pressure can be applied to a gas by applying air pressure to one surface of a fluid, and utilizing the pressure consequently exerted by a separate surface of the same fluid volume. To simplify, methane can be pressurized by forcing water into a container by compressing air over that water in an adjoining container. Check valves ensure that gas and pressure does not escape back into the digester vessel, and that while under compression, gas is only able to move to the pressurized storage container. In the other vessel, the one in which the air pressure is applied, a solenoid would be used to either allow pressure to build up from the air compressor, or to allow air to escape as methane displaces water from the opposite vessel.

Figure 11: Early Concept for a Low Pressure Compression System



Filling Phase:

- A. Gas enters first vessel from digester through check valve
- B. Water is displaced to the other side through plumbed connection
- C. Air escapes through open solenoid so as not to obstruct gas entry
- D. A sensor detects when the water has been completely displaced

Pressurizing Phase:

- A. Solenoid closes and compressor activates when signaled by water sensor
- B. Water is again transferred through connection between vessels
- C. Gas is compressed by rising water surface and escapes to pressure storage
- D. Process continues until a second water level sensor switches the phase

4.1.5 High Pressure Compression

High-pressure compression will be defined, within the scope of this work, as compression of methane within the regime of 1500 to 3000 psi. These bounds are used because they represent the highest pressures at which methane is actually stored in industry. High-pressure compression represents the strategy with the most distinctive advantages and disadvantages. Beginning with the advantages, to compress at high pressure opens up possibilities such as using the gas for transportation fuel. Higher pressures mean greater usability and pressure reliability

and larger storage quantities entail naturally smaller systems. The disadvantages however are equally distinct. High pressure is dangerous, increasing the risk of explosion from vessel rupture and increasing the energy density of the storage. High pressure also requires more expensive pumping equipment and higher quality materials thus significantly increasing the cost.

Were high pressure compression to be implemented for the Nuestro Huerto digester, it would likely take the form of a liquid displacement system very similar to the one described under low pressure compression, with the primary difference being the types of components used. To attain such high pressures the compressor would have to either be purchased at a preventatively high price or fashioned using the water pump from a pressure washer. The solenoids, check valves, and lines needed to operate at such high pressures would also have to be specially acquired, most likely purchased at high cost.

4.2 Analysis

To conduct analysis a decision matrix was employed as described in the methodology. The possible strategies are represented in the rows, and the qualities for which they will be rated are represented in the columns. The bolded decimal fraction in the first row shows the weighting factors with which the rankings will be multiplied to produce a general score. As described in the methodology there are two primary ways to fill out such a table as this, one being to rank the options qualitatively against one another to convert the designer's intuition into a quantitative form and the other being assigning values subjectively in a non-ordinal fashion. The first of these was employed as it involves less subjectivity and therefore tempers the prejudices from the human conducting the decision. With the table filled, the totals are calculated by summing the products of each system's scores and

Table 2: Decision Matrix for Determining General System Type

	Capacity	Pressure	Autonomy	Reliability	Cost	Total
System	0.3	0.1	0.1	0.3	0.2	1
Floating Container	2	2	2	3	4	2.7
Flexible Membrane	4	3	3	4	3	3.6
Direct Output	1	1	1	2	5	2.1
Low Pressure Compression (~150psi)	3	4	5	5	2	3.7
High Pressure Compression (~1500psi)	5	5	4	1	1	2.9

As denoted by the highlighting, the low-pressure compression system was selected numerically given it's receiving the top position in pressure, autonomy, and reliability. This result is at the same time interesting and expected. It is interesting because it shows that the optimum was perceived to exist in between the high complexity of designs such as high-pressure complexity and the performance track record of standard systems such as the floating container and flexible membrane. And it is expected due to distribution of pre-decision conceptual development. It is more than likely that some existing biases played into the decision but the affect they may have had cannot be determined. What is certain is that although systems such the floating container and flexible membrane represent low cost solutions, they do not represent the degree of efficacy desired for a digester of this scale, while more complicated systems are simply not necessary given the volume of gas suspected to be produced. The justification for this assessment can be expressed by breaking down the reasoning behind the decision matrixes rankings. The following sections will do this for each area analyzed.

4.2.1 Scale Factors

The scaling factors were assigned as shown based on the specific needs and concerns expressed by the sponsor. Ranking most highly among the sponsor's concerns are the safety and reliability of the system, and on its functional capacity to store and dispense the output of the digester. For this reason *reliability* and *capacity*

are considered most heavily, with scaling factors of 0.3. Factored in at 0.2 is cost. The system is supposed to be applicable to general sponsors and therefore low capital investment. Commonly available parts are preferable to custom or expensive components. *Pressure* and *Autonomy* are not allotted a very high scaling factor on account of they're being lower priority. Only a small amount of pressure is needed for gas utilization, and autonomy is a nonessential characteristic in a "home-scale" biodigester.

4.2.2 Capacity

Direct output (1; 0gal), having no defined storage, relying on the gas to be produced at the same volume rate that it is to be consumed at all times would be illogical, therefore direct output receives the lowest position in this ranking.

The floating container system (2; 50gal) is visibly the most popular on the home scale and therefore it must have sufficient capacity to couple small digesters to small gas use systems such as cooking stoves and heaters. The container volume in this case dictates the maximum storage. In many cases a roughly 50-gallon vessel is used meaning that in these systems generally do not hold more than that 50 gallons.

The storage capacity in Low-pressure compression (3; 510gal) is dictated by the pressure and volume of the container which holds the gas under pressure. In the case of the Nuestro Huerto site, the most appropriate vessel available is a compressor tank that is estimated to hold roughly 60 gallons in total volume and is rated for pressure up to 125 psi. Because gas under pressure assumes a lower volume proportional to the number of atmospheres (pressure at sea level) that is applied, a 60-gallon tank at 125psi (roughly 8.5atm) is able to contain the equivalent of 510 gallons at 1 atm.

The flexible membrane system (4; 600gal) can be constructed in many different ways. The style that was drafted for the Nuestro Huerto site consists of a thick plastic bag affixed to the rim of a plastic barrel, much the way a garbage can liner might be positioned. What this means for the capacity is that each of these modules (multiple barrels could be used together) would have a theoretical

maximum capacity of 50 gallons for the barrel and another 50+ gallons once the bag has completely inflated out from the barrel. For this system to earn its place in the ranking as many as 6 of these barrels would need to be strung together, a certainly achievable scale given the remarkably low cost associated with barrels and barrel liners.

Leading the pack in storage is the High-pressure storage system (5; 600gal). In this system a container such as a scuba tank would likely be used to contain the relatively immense pressure of between 1500 and 3000 psi. Dividing the pressure in psi by 15psi/atm and multiplying the pressure in atm by the tank volume can again calculate the maximum storage. A low end incarnation of this system using an 80ft³ scuba tank and a 3000 psi Pressure washer would have an equivalent gas storage of around 600 gallons. This system as well could utilize multiple tanks for increased storage.

4.2.3 Pressure

In the category of pressure, the comparison is fairly easily drawn. Systems with no mechanical pumps or compressors must rely on the pressure of the reaction to drive the gas to its point of use. In the first three systems, Direct output (1, <5psi), floating container (2, <5psi), and flexible membrane (3, <5psi), the pressure that the reaction can generate is low, in the order of only a few psi given the reactor vessel limitations and the reaction slowing affect of pressure. The flexible membrane and floating barrel concepts are rated slightly higher though because with them there is to option to close the vessel off from the digester and apply pressure by reducing the volume mechanically, weighting the barrel and pushing on the membrane respectively.

Low (4, 125psi) and high (5, 1500psi) pressure compression rank as they do for obvious reasons. Both of the compression-based systems would be constructed so as to move the gas to a pressurized holding tank, thus eliminating the problem of backpressure on the digestion vessel.

4.2.4 Autonomy

Autonomy in this context means can run unattended and does not require regular checks or input. For the less intricate systems, a lower degree of autonomy is available. Direct output (1) would need to be moderated at any time of use and would otherwise not capture gas. The floating container (2) would be able to fill autonomously unlike direct output, but only receives a 2 in the ranking due to the potential for failure and gas spillage if neglected. While gas is generated in the reactor, the barrel would be constructed to rise automatically to maintain a constant, low gas pressure meaning autonomy for as long as the barrel still has space to rise. If constructed well, when the barrel reached its maximum volume position, gas would be vented from around the downward facing lip and the integrity of the gas would be maintained. However, if the device were not constructed so well an overfilling could result in a failure in which gas not only leaves the space, but oxygen from the atmosphere could enter and become an explosion risk. This failure mode is present in any case that the lip of the container is able to break the water's surface.

The flexible membrane (3) receives a slightly superior mark to the floating container because there is both a higher capacity and a lower chance of negligence related failure. The flexible membrane system would be able to fill unattended until all of the modules were filled, and at that point extra gas would be vented through a U-Bend style pressure relief.

High pressure (5) and low pressure (4) compression receive high marks due to their employment of rigid, standardized containers, automatable components, and powered compressors. These systems stand the highest chance of actually being automatable, that is, made to operate continuously without the need for human actuation until the point of application. The reason high pressure receives a lower mark than low pressure is because of the scale of the components that would be required to introduce autonomy to such a high pressure system, valves, sensors, and actuators become significantly more expensive when designed for the high pressure regime outlined for high pressure compression.

4.2.5 Reliability

Reliability, being among the most important qualities that a gas-capture solution possesses, is scaled relatively High in the decision matrix. Reliability entails both the capacity of a system to operate continuously while requiring the fewest and least burdensome replacements and maintenance, and a low likelihood of undergoing catastrophic failure. Given the cost of the components, and the incredibly high pressures involved, high pressure compression (1) receives the lowest mark. In a system charged to 1500psi a failure could mean several things. It could mean a costly replacement of a line, valve, or vessel, and it could mean a life threatening explosion. Direct output (2) receives a similarly low mark but for a very different reason. The direct output arrangement does not threaten user safety to nearly the extent as high-pressure compression, however it threatens the effectiveness of the process and the integrity of the vessel. When pressure builds in the closed space it both slows the methane development and applies stress to the walls of the cube shaped vessel, threatening the structure of the system. Pressure would have to opportunity to build with the direct output system because the gas would only be allowed to escape during times of use and otherwise would necessarily remain inside the vessel. The floating container (3) receives higher marks for reliability because if constructed properly, it would function reliably in nearly all respects. The reason that the floating container does not receive the highest ranks is due to its potential propensity to topple and “spill” collected gasses to the atmosphere or introduce dangerous oxygen if constructed less than optimally. The flexible membrane solution (4), receives a higher mark due to the nominal pressures entailed, but still not the top rank due to the vulnerability to puncture opened up by utilizing a rubber or plastic membrane. Were the flexible membrane to be implemented using the nested contractor bag arrangement as described above, the puncture risk would be quite high, and best mitigated by insulating the plastic membrane with a tarp or burlap to prevent direct contact with objects that might cause a rupture. Low-pressure compression (5) receives the highest mark because it naturally avoids the major negative aspects of most of the others. It uses common

components unlike high-pressure compression. It holds a constant pressure against the reactor vessel unlike the direct output. The primary storage container is fully enclosed, unlike the floating container. It uses rigid, puncture resistant, vessels and lines unlike the flexible membrane.

4.2.6 Cost

The cost of a solution is a critical aspect, not only in that one should enact the most cost effective solution but also in that one must know if the system is even going to offset the installation costs with the energy and fertilizer savings. In the case of the Nuestro Huerto site however, the digester is already in place, and a gas capture system will be necessary regardless. For the purpose of decision-making, much of the cost data will be estimates based on the sum costs of the major components involved. The figures that will be generated are not meant to accurately describe the total price of installing the system, but more represent to major expenditures.

High pressure compression (\$200, 1)

- Scuba Tank: ~\$40 from Craigslist
- 1500psi electric pressure washer: ~\$60 from craigslist
- Valves and solenoids: >\$100 total from MSC Industrial Supply

Low pressure compression (\$240, 2)

- High volume compressor tank and compressor: ~\$200 from craigslist
- Transfer tanks: ~\$10 from salvage yard
- Solenoids: ~\$10 from Amazon
- Hoses and fittings <\$20 from any local hardware store

Flexible Membrane (\$155, 3)

- 6X ~50 Gal drum: at \$20/ea, ~\$120 from craigslist or salvage
- Contractor bags: \$15 from any local hardware store
- Hoses and fittings: <\$20 from any local hardware store

Floating Container (\$60 , 4)

- 2X ~50 Gal drum: @\$20/ea, \$40 from craigslist or salvage

- Hoses and fittings: <\$20 from any local hardware store

Direct Output (\$20, 5)

- Hoses and fittings: <\$20 from any local hardware store

As is shown, there is a large range in potential costs for the systems proposed. Again, the above figures are generated in a cursory fashion, to demonstrate the effective relative costs of the systems given the costs of major components. The figures here are in no significant way indicative of the actual cost should any of these systems be realized. Fully designed costs would likely be higher.

Using the data presented above to justify the calculation in the decision matrix, a design decision can be made with greater confidence. That decision will be to use the low-pressure compression system.

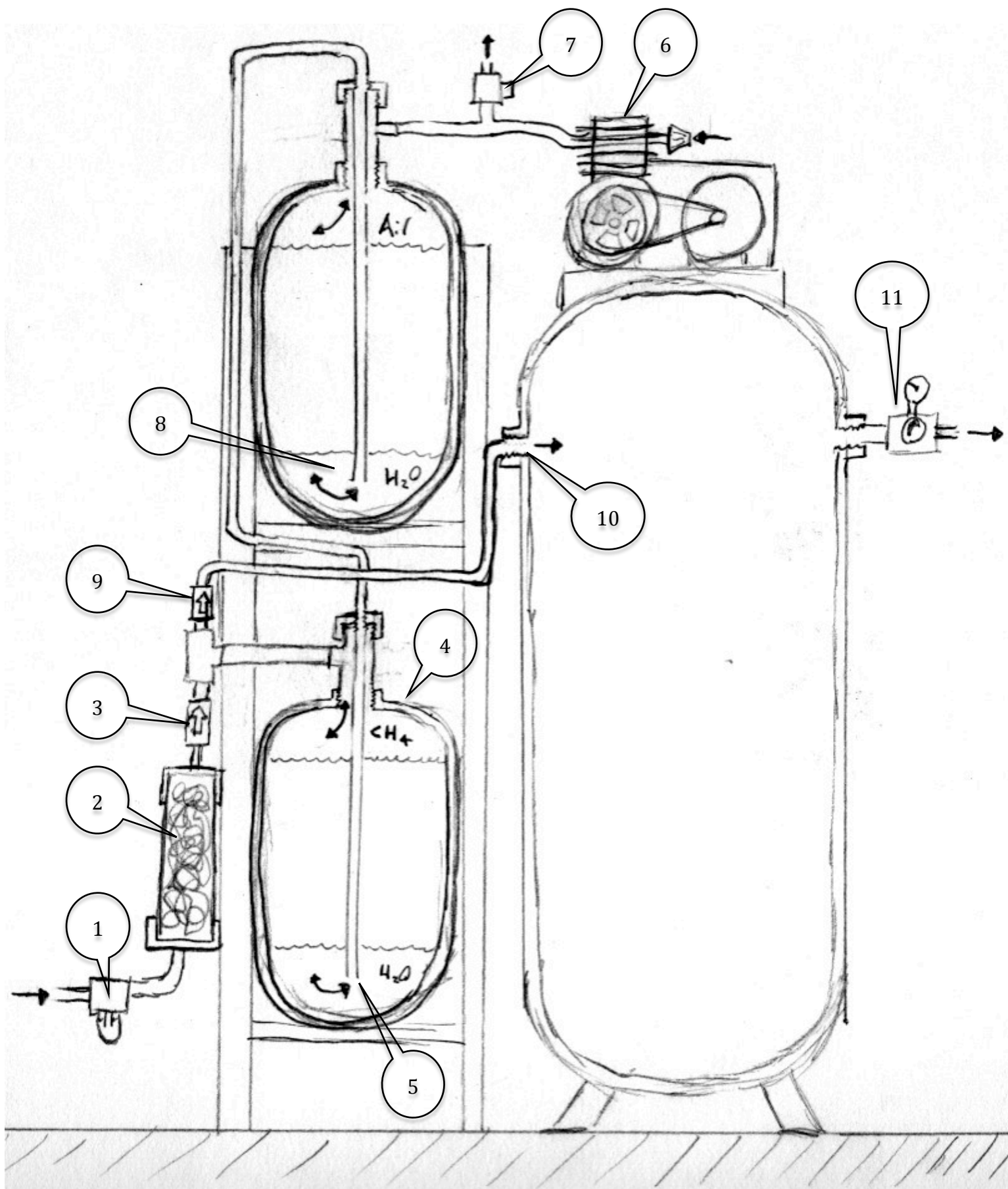
5.0 Results

Because no prototype is to be constructed within the scope of this work, the results will consist of a fully designed concept, construction sketches, and a bill of materials. Most of the research outcomes and numerical findings have been expressed in the Design section, and thus this section merely serves to tie up the choices made and illustrate the design conceived.

As written above the low-pressure compression solution was chosen due to its combination of relatively high capacity, safe yet functional pressures, use of common and available components, and capacity to be automated. The system will use the method of applying air pressure to the surface of water in one tank, and transferring that pressure to the gas in another container through the water. The containers will be arranged vertically so that in order for incoming gas from the digester to displace water, it must necessarily overcome a small backpressure, thus ensuring that ambient air intrusion into the digester is avoided. The ultimate storage vessel would optimally be that of an upright air compressor so as to remain space efficient and to give the compressor itself a secure base of attachment. The fully designed system is shown on the next page with numbered component callouts, which are listed on the following page. A design such as this could be positioned either next to the digester inside the greenhouse, for accessibility during winter operation, or it could be stationed outside for better space management. Were the system to be positioned outside, measures would need to be taken to prevent the transfer water from freezing such adding an antifreeze additive to the water.

Were the system to be automated, it would simply require the addition of a microcontroller to coordinate functions, a solenoid to replace the air escape valve, a power relay to control the compressor, and sensors to determine the water level in one or both of the transfer vessels. Such automation could greatly improve the reliability of the system by eliminating the need for a human operator to control the individual elements. Automation would not only be advantageous, but would come recommended to ensure the system's proper function.

Figure 12: Detailed Concept For Low Pressure Compression System



5.1 Process Phases and Steps

Refer to previous page for diagram and callouts.

Table 3: Numbered Callouts and Steps

1	Gas enters from the digester vessel, and is first passed through a descant filter to remove water vapor and particulate solids from the digestion process.
2	Water vapor is removed so as to prolong the life of the next filter, the hydrogen sulfide scrubber, a PVC compartment that can be stuffed with sacrificial steel wool which is oxidized to iron sulfide thus reducing any corrosive H ₂ S gas to water vapor. (Filter)
3	Gas passes through a check valve, which serves to isolate the gas-in line from pressure during compression cycles.
4	Gas enters the lower displacement vessel under it's own pressure, displacing water which had been moved in during the previous compression cycle.
5	Water that is displaced by the incoming gas is pushed up the "Keg Style" transfer line to the upper transfer vessel. This change in elevation is responsible for the development of backpressure, a small amount of which is beneficial to the stability of the digester.
6	Whether or not the system is automated there would need to be a sensor, indicator, or float valve to indicate when the filling transfer is complete and it is time to activate the compressor to begin the compression phase.
7	Simultaneous to the activation of the compressor, the air escape valve would need to be closed, either manually or by a solenoid. This allows pressure to build over the surface of the water in the upper transfer vessel instead of being vented to the environment as during the filling phase when the valve is open,
8	Water is pushed through the transfer line by the building air pressure in the opposite direction as before. This applies pressure to the gas which is in the lower vessel.
9	The gas, now under pressure, cannot leave through the check valve discussed in step 3 and so must build pressure until it can flow through a second check valve.
10	Because the aforementioned check valve is adjacent to the main vessel, gas can only enter once it has reached the elevated pressure and density present in the storage tank.
11	Gas at pressure can be utilized now, by way of a flow regulator, which will bring the pressure and flow rate down to ones which are acceptable for the end use, be it cooking, heating, or generating.

5.2 Bill of Materials

This rough bill of materials should create a more accurate picture of the materials and costs involved in building this design. Costs should still not be expected to be completely accurate as many of the components are sourced from unpredictable sources such as craigslist or salvage yards. Other components are sourced from local hardware stores.

Table 4: Bill of Materials

Item	Quantity	Source	Price
Compressor	1	Craigslist	\$200
Main Storage Tank	1	Craigslist	Included with compressor
Transfer Tanks	2	Salvage Yard	\$5
Check Valves	2	Amazon	\$5.86
Solenoid	1	Amazon	\$8.34
Relay	1	Home Depot	\$4.99
Microcontroller	1	RadioShack	\$29.99
Desiccant Filter	1	Harbor Freight	\$7.99
Regulator	1	Harbor Freight	\$13.99
¾" Threaded Pipe Nipple 2"-6"	2	Home Depot	\$1.57
¾" Pipe Cap	2	Home Depot	\$1.96
¼" Pipe Barb	10	Home Depot	\$2.80
¼" male-male connector	2	Home Depot	\$0.98
¼" female-female connector	1	Home Depot	\$3.87
Misc. Hardware		Home Depot	\$20.00
Total	28		\$347.91

6.0 Conclusion

There are several conclusions that can be drawn from the current state of design and research, yet there are many more that cannot. The intention of this project was to draft and propose a design for a gas handling system to work with the digester that is installed at the Nuestro Huerto site; five systems were evaluated and, as discussed above, the low-pressure system was seen to be the best fit. As for the efficacy of the system, that will remain to be seen as no prototype has been constructed.

Looking forward, it can be expected that some variant of this design, or the design exactly as it is given will be implemented at the site, although it is not entirely necessary that the design selection be heeded. The solution given here is by no means the only viable solution. The top four on the decision matrix are all viable solutions, leaving only direct output as a truly invalid option. The floating container is very popular, being the choice of almost every other home scale digester made. The flexible membrane system could cheaply be made to hold very large quantities of ambient pressure gas. Although it scores well, high-pressure compression is also in a way discounted. The high pressures involved make sourcing parts difficult and expensive, and its incredibly high energy makes it a safety hazard, which counts against it as safety is among the sponsor's chief concerns.

Throughout the process of designing the proposed solution, it was often tempting to try to incorporate long-shot technologies and solutions. Another of these was the possibility of using centrifugal compression and refinement. In researching refinement technology it was found that in industry the separation of methane and carbon dioxide in biogas is generally done using a semipermeable membrane, but with that technology not financially viable some creativity could be used to separate the two gases by their densities. Separation by density would best be done using a centrifuge, which could potentially serve the double duty of compressing the gas.

Long-shot solutions aside, there should, at this point, exist a detailed enough concept for biogas compression to be implemented, at least in the form of an initial test system. Given the implications of civilian biogas production it is important that development be made, both in technology and in accessibility. The systems discussed in this work are not innovative concepts; they have existed in other settings for some time now, but it is the context and utilization that marks the intention behind developing a system like this. When technology from the industrial world filters into small-scale systems, such as urban agriculture, it can be empowering, provided that it is presented in a way that is accessible. The purpose of the project was not to develop a technology, but to understand the needs and interests of the sponsor, to package the technology, to emulate it using consumer materials and at price scales accessible to Nuestro Huerto. More work will need to be done before a cheap, reliable, and manageable anaerobic digester can be implemented at every waste producing facility, but research in the urban agriculture scene is certainly an appropriate place to begin.

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